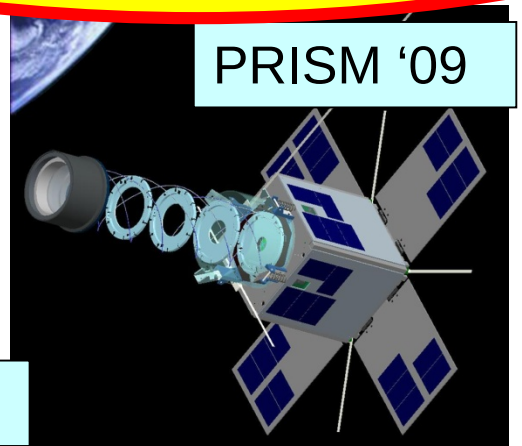

PROCYON ‘14


Hodoyoshi-1 ‘14

# Small and Micro/nano-satellite Possibilities in Space Science and Exploration - Examples from Japan -

Shinichi Nakasuka and Ryu Funase
University of Tokyo


CubeSat 03,05


PRISM ‘09

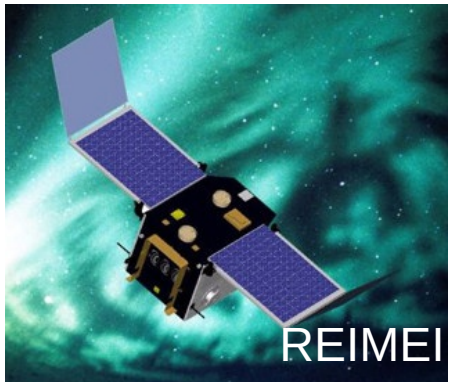

Nano-JASMINE ‘17

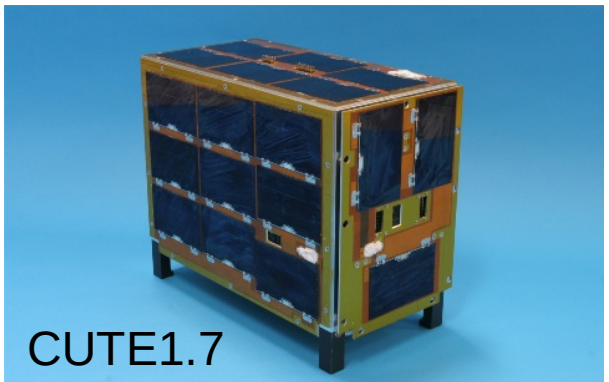
# Overview and Contents

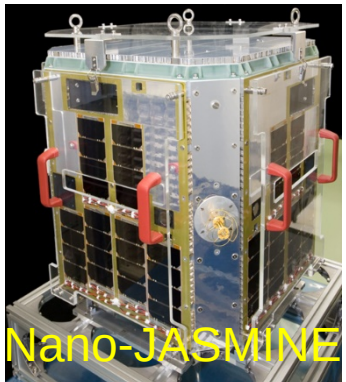
- Three streamlines of space science and exploration projects in Japan
  1. JAXA/ISAS has excellent history of space sciences using small-large(3t) satellites
  2. Universities started own contributions using micro/nano/pico-satellites (since 2003)
  3. University-JAXA joint missions for space exploration started in 2013 with PROCYON
- University of Tokyo's contributions in micro/nano/pico-satellite fields
- Key strategies to pursue science missions using small/micro/nano/pico-satellites

# Space Science and Exploration
# - Japanese Missions and Players -

| Size(kg) | Category | Players | Project Examples |
|---|---|---|---|
| >500 | Mid-large | JAXA | Science: Ginga, Akari, Suzaku, Hitomi—<br>Exploration: Hayabusa & 2, Kaguya, Akatsuki-- |
| 100-500 | Small | JAXA | Science: Hisaki (2013), ERG (2016) ----<br>Engineering: Ikaros (2010) |
| 20-100 | Micro | JAXA<br>University | Science: Reimei (Index, 72kg, 2005)<br>Nano-JASMINE(38kg, 2017), RiseSat (2018)<br>Exploration: PROCYON (58kg, 2014) |
| 2-20 | Nano | University | Science: CUTE-1.7+APD II (3kg 2008)<br>Exploration: ECUULEUS (6U EM-1 2018) |
| <2 | Pico | | |


REIMEI


CUTE1.7

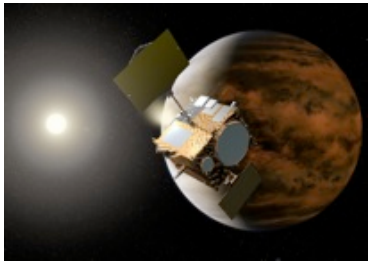

Nano-JASMINE


PROCYON

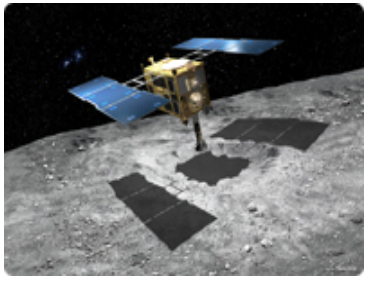
# JAXA: “Larger than small-satellite” Exploration Projects

Kaguya: Japanese first lunar orbiter. Improved global topography maps, global gravity map and observation of shadowed interior of the crate, etc (**2.9t**, launch 2007)

Hayabusa :Challenging space technology demonstration leading to the birth of a new pillar in planetary sciences. Returned and asteroid dusts obtained, and samples are under investigation. (**510kg**, launch 2003, return 2010)



Akatsuki : Understanding the atmospheric dynamics and cloud physics of Venus, Succeed in inserting into Venus orbit in Dec 2015. (**500kg**, launch 2010)

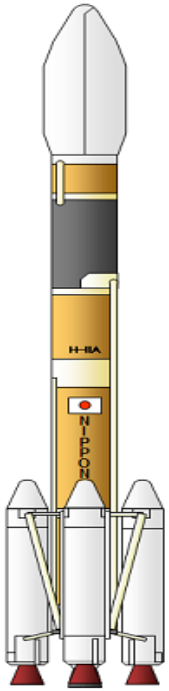


Hayabusa2: Targeting at an asteroid whose samples enable us to address the ultimate science question related to our origin. (**600kg**, launch Dec 2014)

# JAXA/ISAS's Small Satellite Space Science Program (300～600kg)

# JAXA/ISAS Strategy for Space Science Programs

## Space Science Projects are becoming more & more diversified




**ISAS strategic mission (cost: $200M-300M)**

**Flagship mission to be led by big Japanese communities with large-scale world-wide collaboration (H-2A Rocket)**

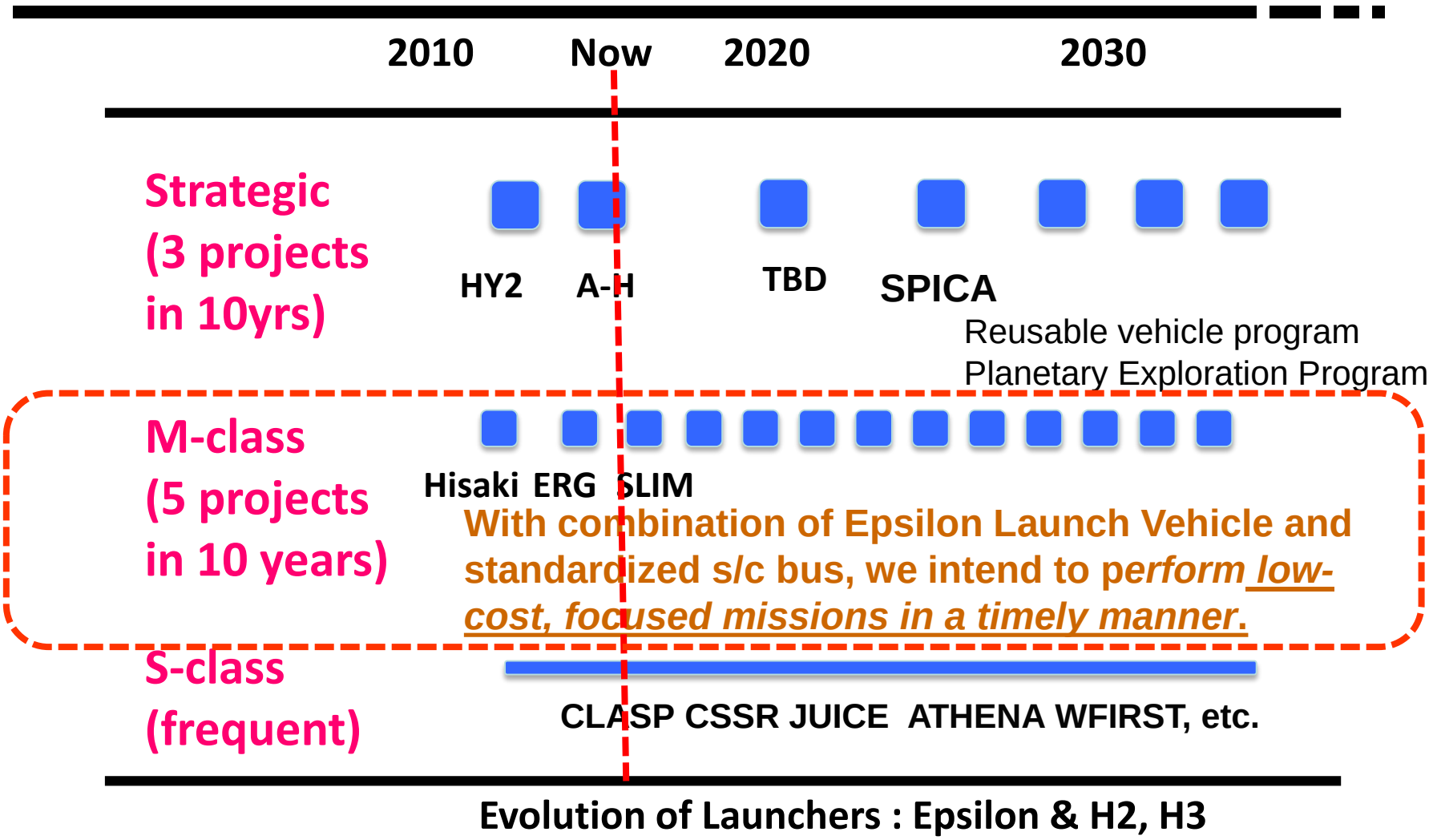
**M-class mission (300-600kg size) (< $100M)**

**Has more focused, challenging missions. Frequent opportunities provided with lower cost and Epsilon launch. Also including planetary exploration using "enhanced Epsilon".**

**S-class mission (<$10M)**

**Missions with science payload development which will be onboard on foreign missions, or small projects using balloons, sub-orbital rockets and micro-satellites.**

# ISAS Space Science Roadmap



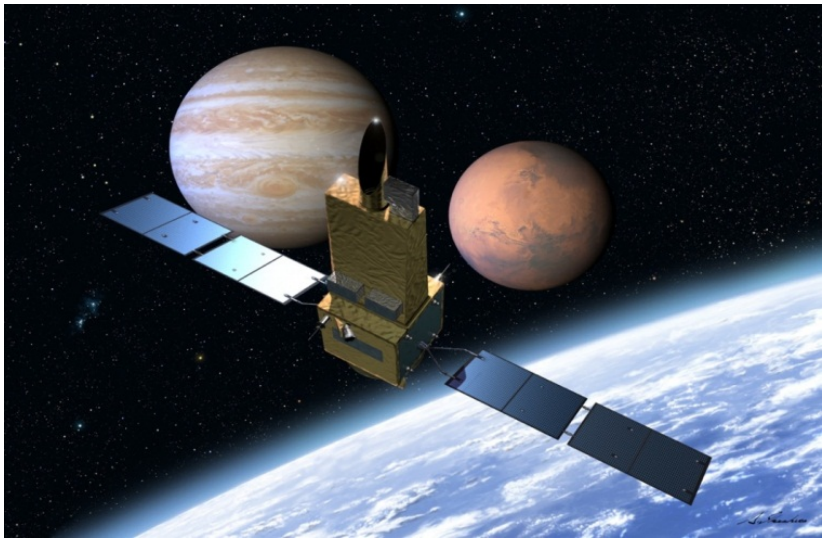

Project cost range (rough image)

Strategic: $200-300M  M-Class: around $100M  S-Class: <$10M

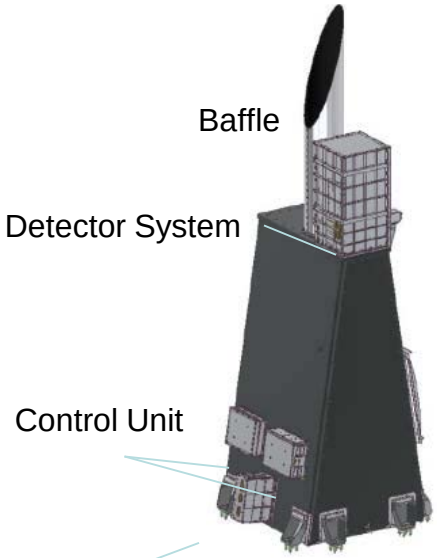
# M-Class (1): SPRINT-A/EXCEED (HISAKI)

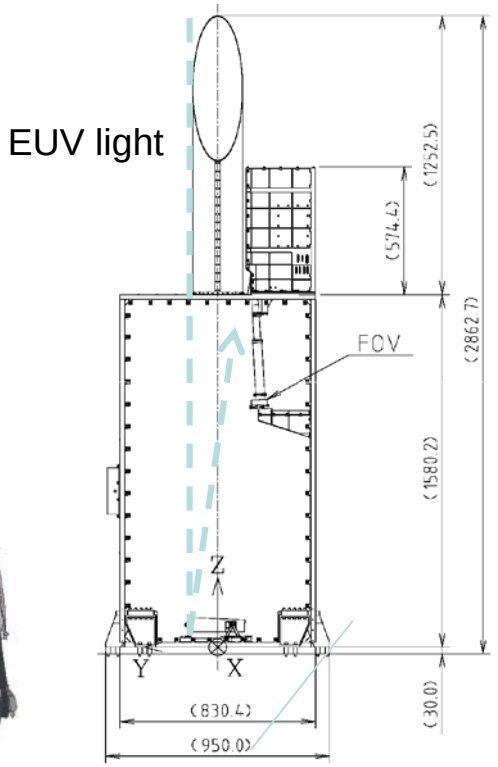
**Launched on 14 Sep. 2013 (335kg) on first Epsilon rocket launch**

- **Ex**treme ultraviolet spectros**C**ope for **E**xosph**E**ric **D**ynamics
- The mission is spectroscopic and imaging observation of EUV (extreme ultraviolet: 60-145nm) emissions from tenuous plasmas around ***Venus, Mars, Mercury, and Jupiter***.
  - measuring the plasma escape rates from the terrestrial planets (Venus, Mars, and Mercury)
  - understanding the electron energy and density distribution around the Jovian inner magnetosphere.



SPRINT-A/EXCEED



# M-class (2) ERG (Energization & Radiation in Geospace)

**Planned to be launched in FY2016 (350kg)**

ERG is a mission to elucidate acceleration and loss mechanisms of relativistic electrons of Van Allen belts during space storms.

**Significance of the project:**

- Direct observations on generation of relativistic electrons at the magnetic equator in the inner magnetosphere
  → contribution to understanding of the particle acceleration.
- Instrumental development to measure plasma and fields under the incidence of radiation belt particles with small satellite
  → contribution to a future Jovian mission.
- Understanding the acceleration and loss mechanisms.
  → contribution to predictable space weather model for space radiation environments.

# M-class (3) SLIM (Smart Lander onto the Moon)

**Planned to be launched in FY2019 (520kg)**

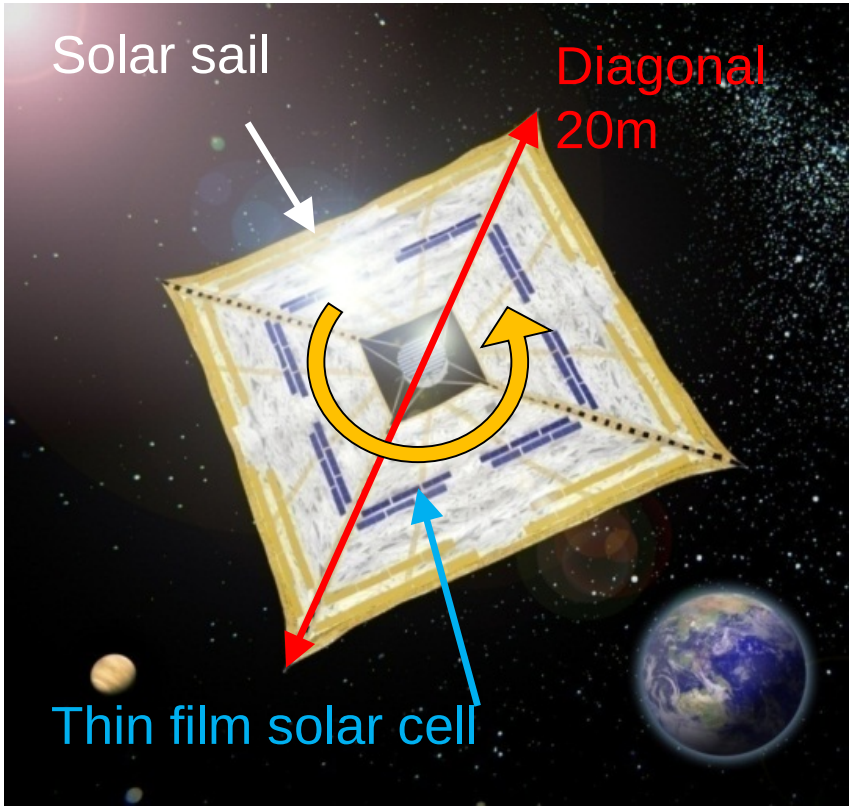
SLIM is a mission to demonstrate the technology for pin-point (about 100m accuracy) soft landing on lunar surface.

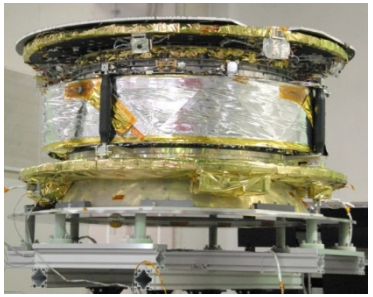
- Technology demonstration with Small Spacecraft
  - Image-based Navigation utilizing Lunar Terrain
  - Autonomous Obstacle Detection
  - Robust Pin-point Guidance
  - Landing Shock Absorber
  - High-performance Propulsion
  - Exploration using Spectrimeter or Tiny Rovers (option)
- Frequent trials of lunar/planetary surface exploration technology
- Precursor of future full-scale lunar or planetary missions

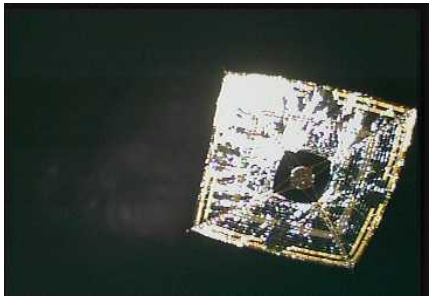
# (Piggy-back) IKAROS: A Solar Sail Demonstrator

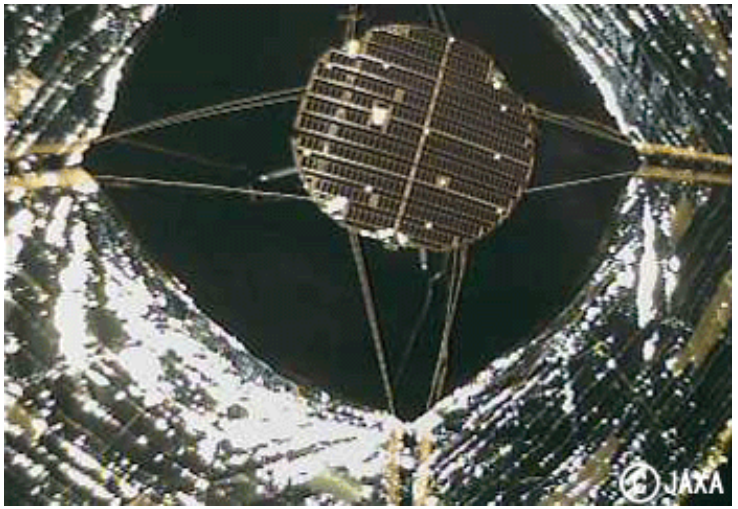
**IKAROS (= Interplanetary Kite-craft Accelerated by Radiation Of the Sun) is the world's first interplanetary solar sail craft which demonstrated its photon sailing and thin film solar power generation**

- (**310kg**, launch 2010 as piggyback)



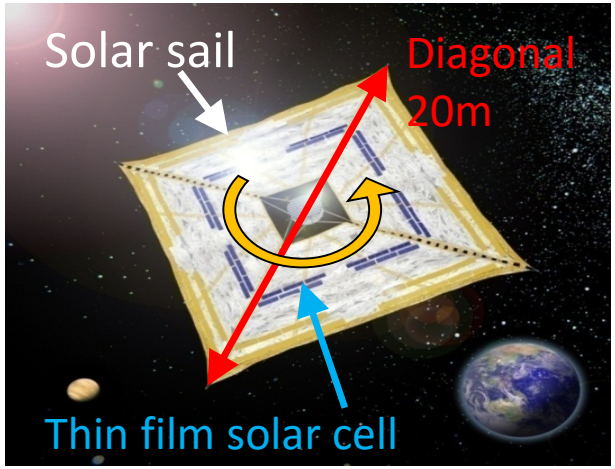








**DCAM(Camera-craft) captured solar-sailing IKAROS June 14, 2010**

# IKAROS Succeeded in Solar Sailing (2010)




Launch
(21/May/2010)

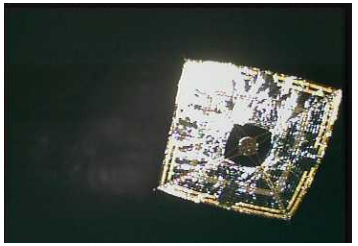
~9/June/2010

~10/June/2010

Nominal operation phase
(May/2010 - Jan/2010)

(for six months)

Extended operation phase
(Jan/2010 - now)



Venus Flyby
(8/Dec/2010)

[Tech. Demo. #4]
Solar sail guidance, navigation and control

[Tech. Demo. #3]
Photon propulsion

[Tech. Demo. #2]
Power generation by sail-mounted thin film solar cells

[Tech. Demo. #1] Solar sail deployment

Led by JAXA Lunar & Planetary Exploration Program Group

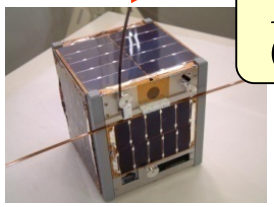
# Micro/nano/pico-satellite space science/exploration projects driven by universities (1～100kg)

# University of Tokyo's (UT's) History - 8 satellites developed (7 launched) -

2003 04 05 06 07 08 09 10 11 12 13 14 15

30m GSD Remote sensing

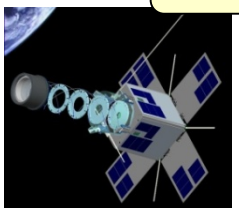
[1] Education, Camera test



**CubeSat XI-IV**
(ROCKOT) 2003/6

World First CubeSat !

[3]

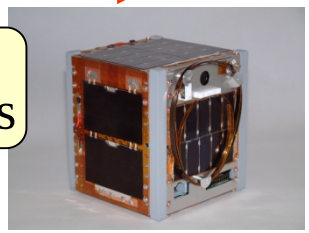


**PRISM**
(H-IIA) 2009/1

[8] Astrometry (top-science)

**NANO-JASMINE**
2017 (TBD)

[2] Education, CIGS solar cells

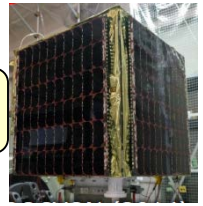


**CubeSat XI-V**
(COSMOS) 2005/10

[4][5][6] Remote sensing, S&F

**HODOYOSHI-1,3,4**
(DNEPR) 2014/6,11

[7] Deep space exploration



**PROCYON**
(H-IIA) 2014/12

[1]-[7]:Launched and being operated in space
[8]: Waiting for launch

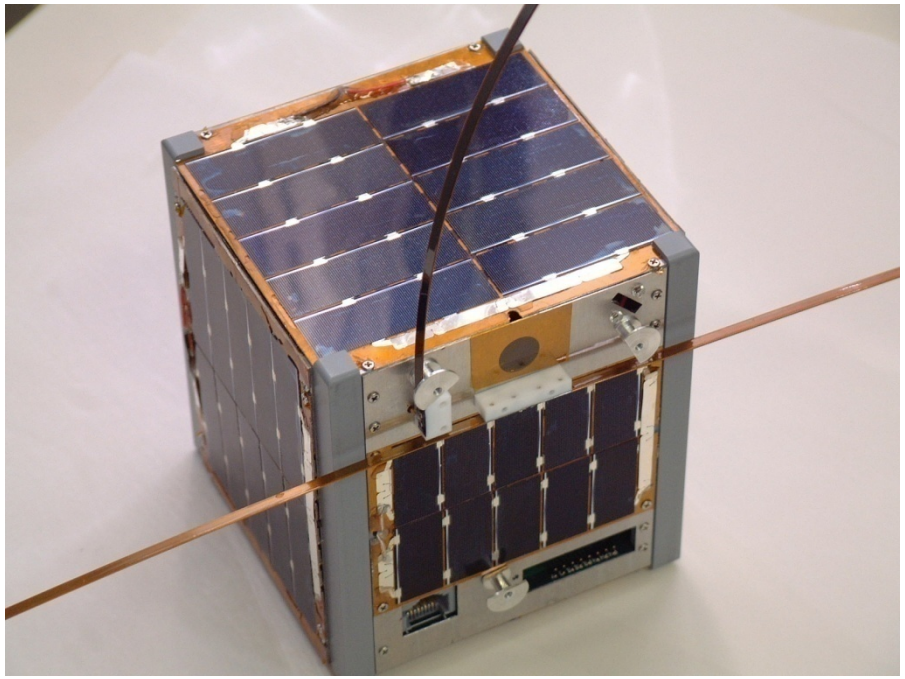
→ development ▼ launch

# CubeSat "XI-IV (Sai Four)"

Intelligent Space Systems Laboratory
University of Tokyo
ISSL

Mission: Pico-bus technology demonstration in space, Camera experiment
Developer: University of Tokyo
Launch: ROCKOT (June 30, 2003) in Multiple Payload Piggyback Launch

| | |
|---|---|
| Size | 10x10x10[cm] CubeSat |
| Weight | 1 [kg] |
| Attitude control | Passive stabilization with permanent magnet and damper |
| OBC | PIC16F877 x 3 |
| Communication | VHF/UHF (max 1200bps) amateur frequency band |
| Power | Si solar cells for 1.1 W |
| Camera | 640 x 480 CMOS |
| Expected life time | ?? |

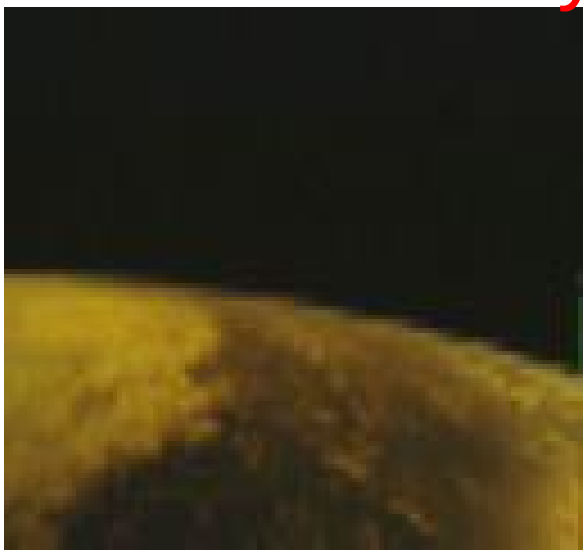
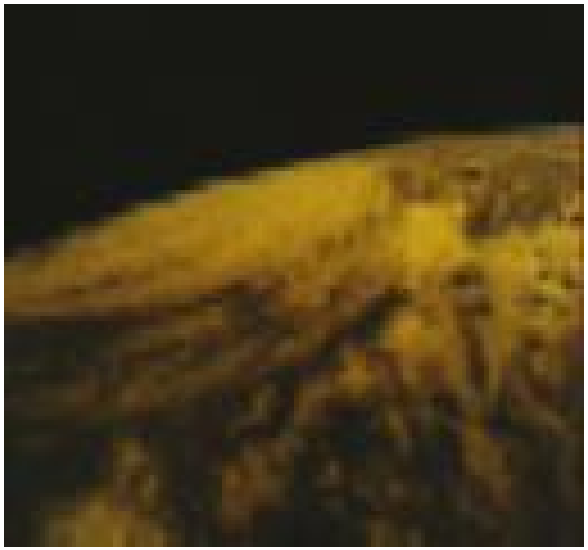


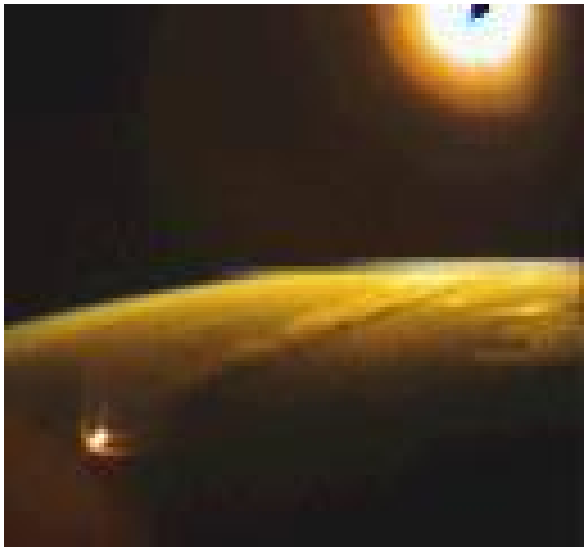
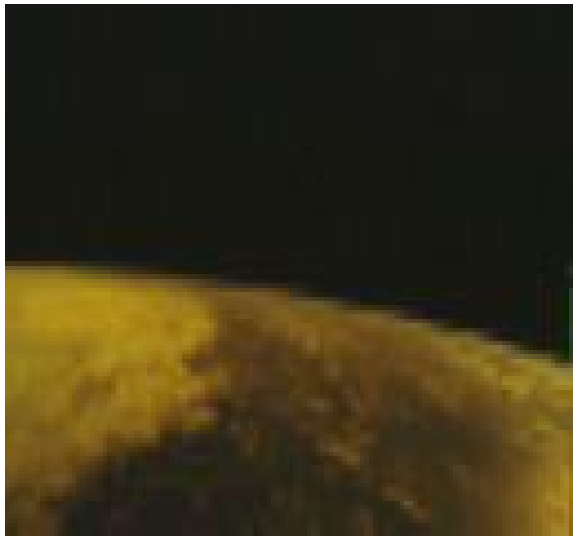
Captured Earth Images are Distribution to Mobile Phones

# XI-IV is still perfectly working after 13 years in orbit

Sepia color !
Get older ?

## Recently Downlinked Photos

# UT's 4th Satellite:Nano-JASMINE

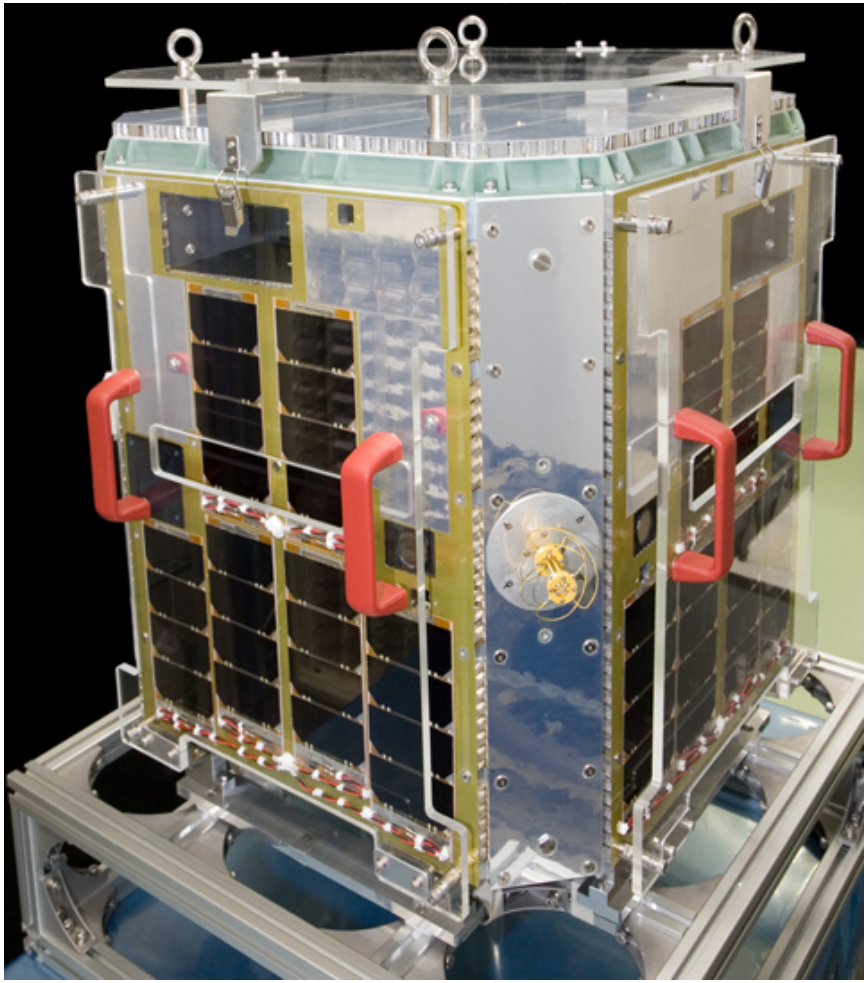
Intelligent Space Systems Laboratory
University of Tokyo
ISSL

Mission: Astrometry (Getting precise 3D map of stars and their movements)
Developer: University of Tokyo, National Astronomical Observatory of Japan, Shinshu University, Kyoto University
Launch: Initially CYCLONE-4 was planned but changed to another launcher

| | |
|---|---|
| Size | 50 [cm-cubic] |
| Weight | 38 [kg] |
| Attitude control | 3-axis stabilization with Star, Sun, Magnet sensor, FOG, RW, Magnetic torquers |
| OBC | FPGA |
| Communication | S-band 100 [kbps] |
| Mission life | 2 [year] |

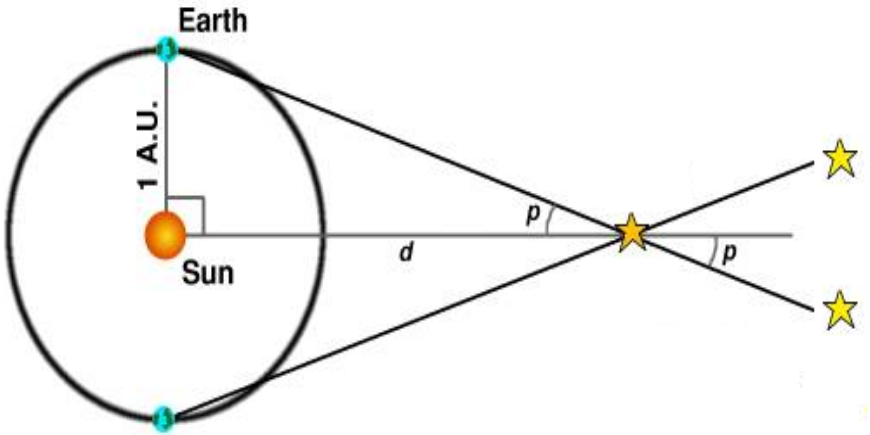
Special features:

| | |
|---|---|
| -Attitude Stability | 0.8 arcsec for 8.8 sec |
| -Thermal Stability | < 0.1K (at -50 degree) |
| -Map Accuracy | Compatible with "Hipparcos" Satellite ('89) |
| -Telescope | two CCDs with TDI |



# NJ's "Astrometry" Mission

- **Mission**
  - **Estimate 3 Dimensional positions of stars and their movement ("Astrometry")**
  - **Pre-cursor for "JASMINE" series**




**Star position determination by**

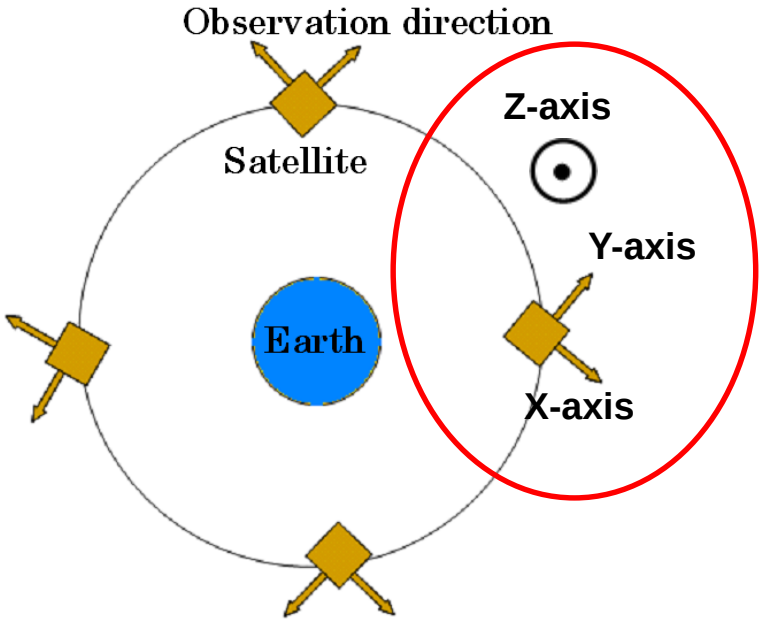
**Annual Parallax**

- **Attitude stabilization**
  **0.8 arcsec / 8.8s**
- **Temperature stability**
  - **50℃, ±0.1℃**

- Long exposure time required.

- Separation angle between two telescopes should be kept constant.

# Star Observation using TDI



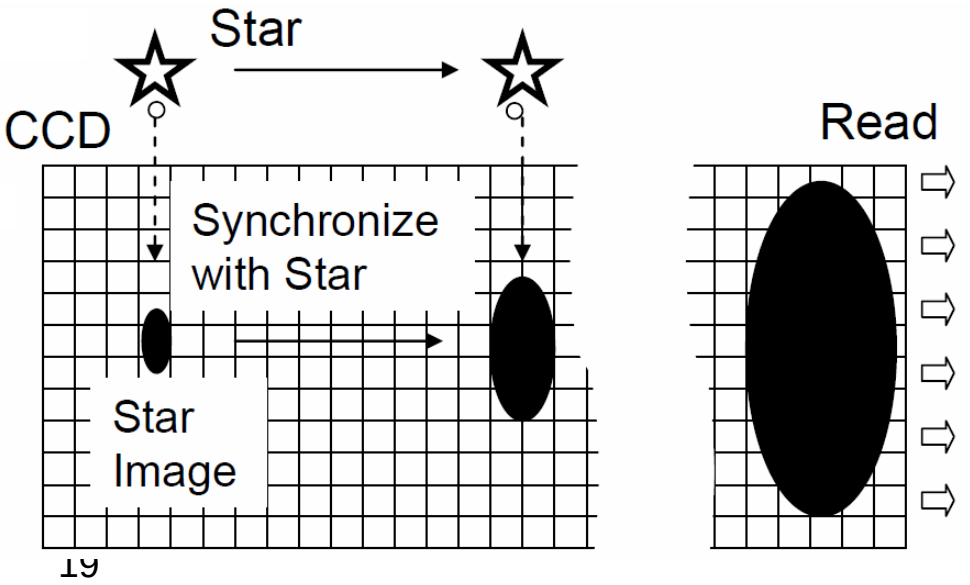

**Time Delayed Integration (TDI) using special CCD sensor**

**Spin rate is synchronized to capacity transfer speed on CCD to get long exposure time**

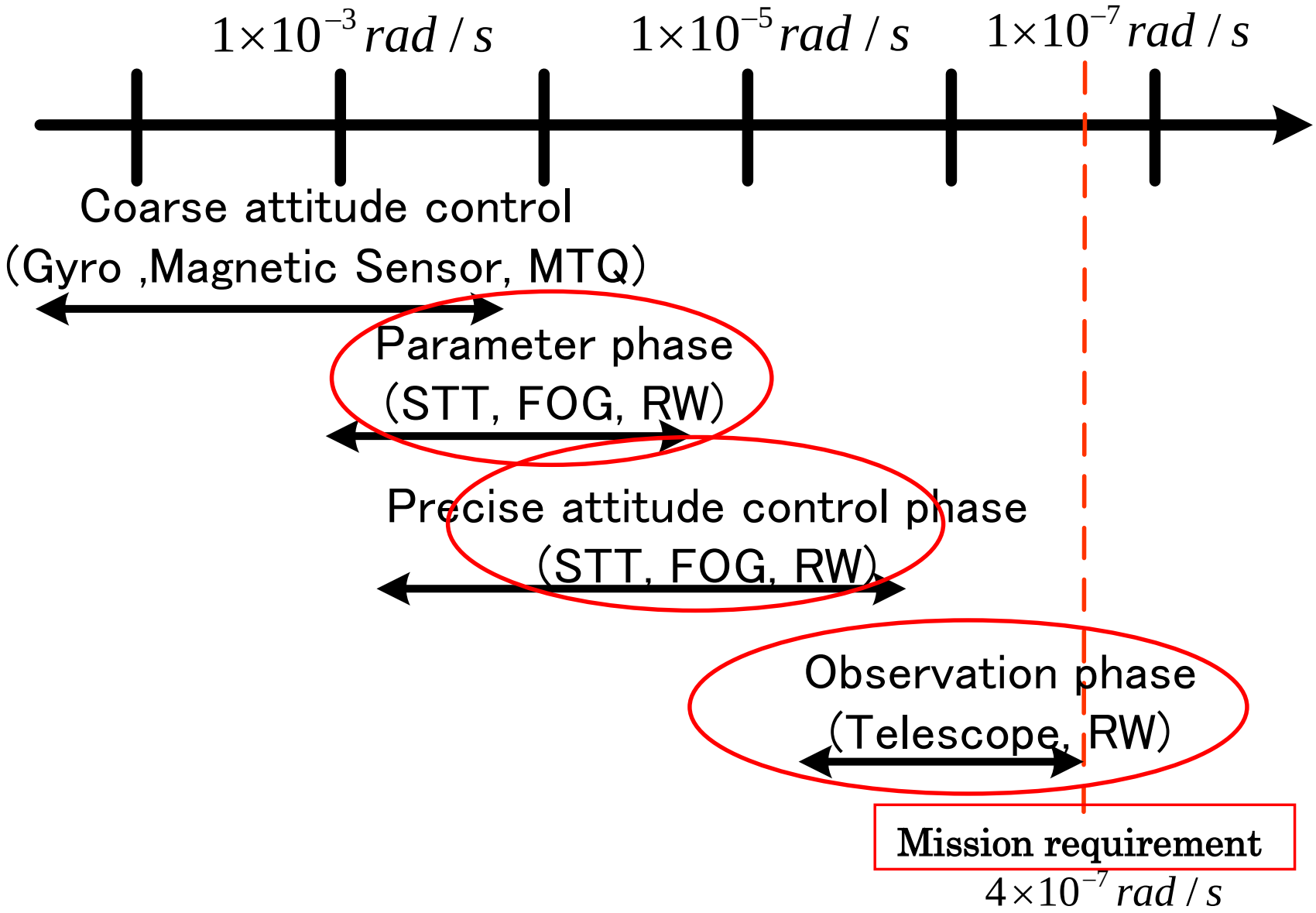
**X, Y->Observation direction**

**Z-> Spin axis in orbital period**

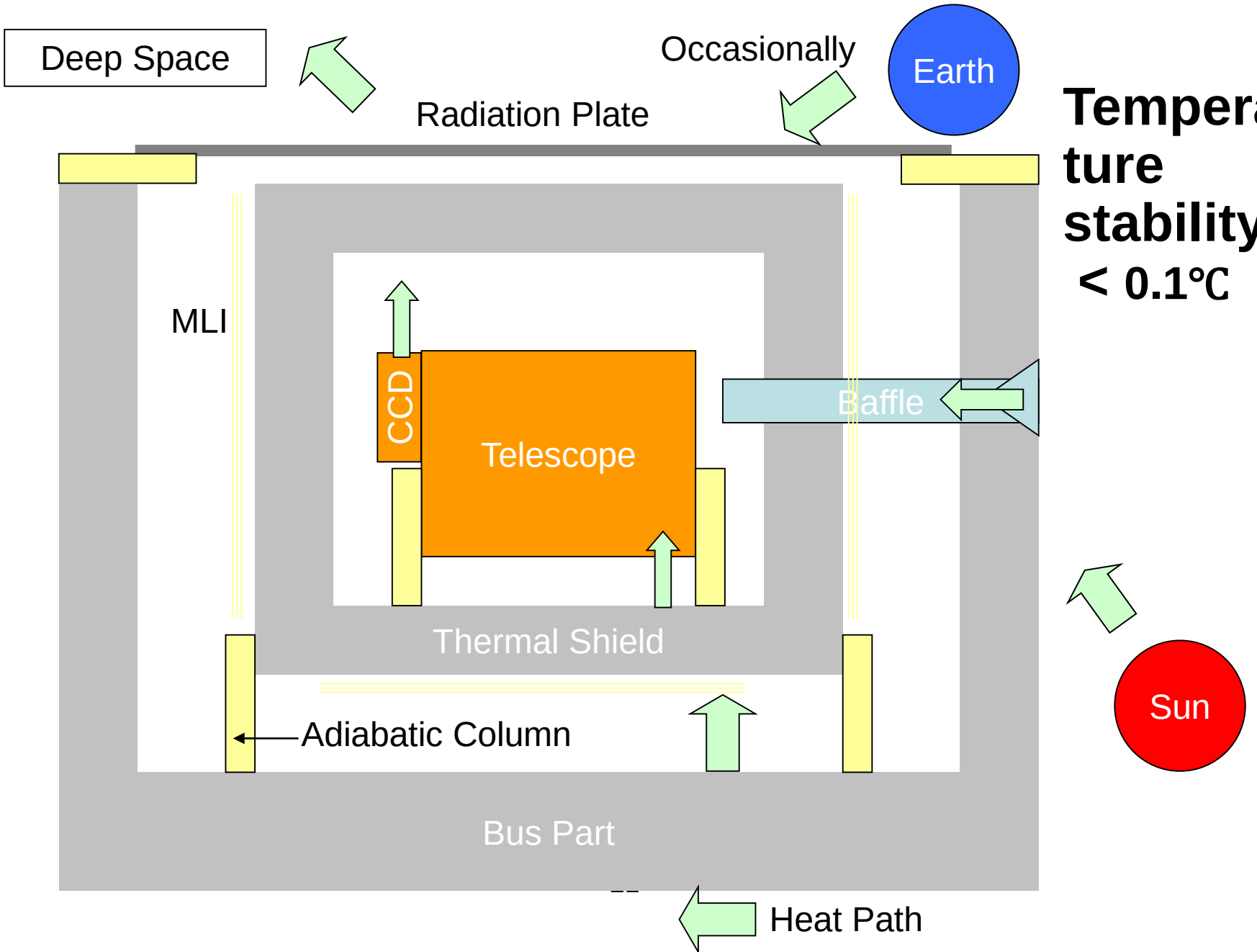
4 x $10^{-7}$ rad/sec level stability is required



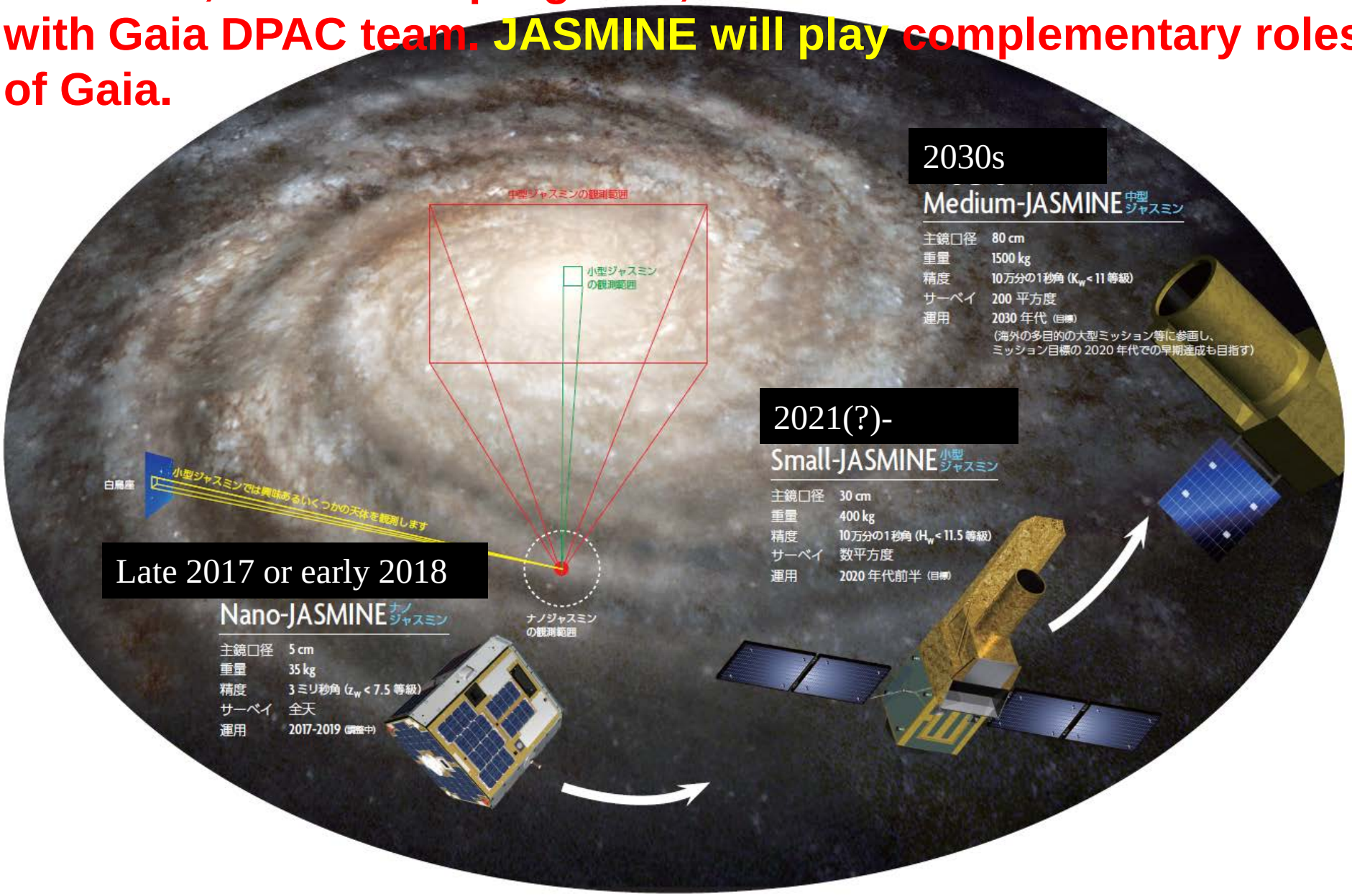
# Strategy to Achieve High Attitude Stability



# Sever Thermal Stability is Achieved by:



**Japanese group is promoting series of space astrometry missions, “JASMINE program”, in international collaboration with Gaia DPAC team. JASMINE will play complementary roles of Gaia.**



# University Satellites in Japan

## 37 university satellites launched in 2003-2015


From CanSat to CubeSat, Nano-Satellite

From Educational purpose to Practical applications

# “Hodoyoshi-Project” to Establish Infrastructure for Micro-satellites in Japan (‘10-’14)

Low cost supply chain network

“Hodoyoshi”(good enough) reliability

Satellites, components, infrastructure with high competitiveness

New Paradigm of Space Development and Utilization

Low-cost, Quick, Practical level

Human Resource Training

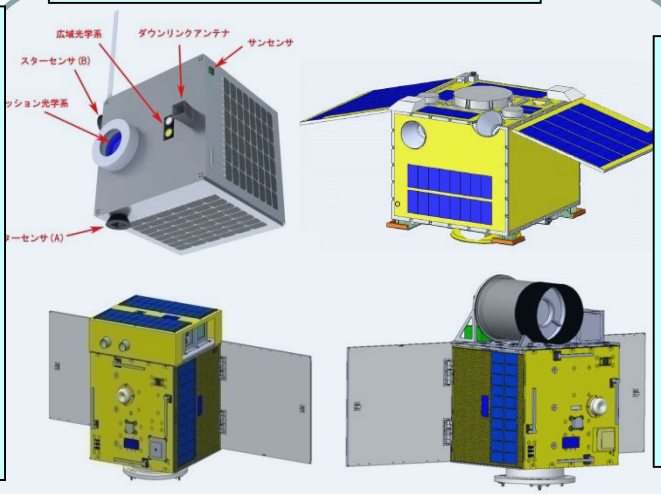
**Development Process**

Miniature components

Advanced components

Optical system, Image processing

Tech. Demonstration




Four satellite development

Infrastructure

Promotion

Ground Station

Ground Testing

[Standa-rdization]

Personal use
Novel missions
Foreign Customers

**Novel Missions Demo.**

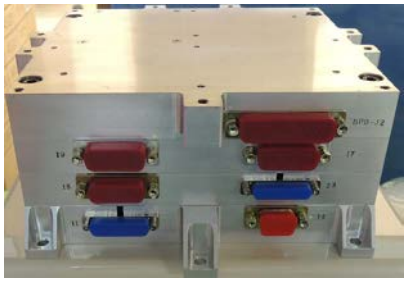
Mission creation

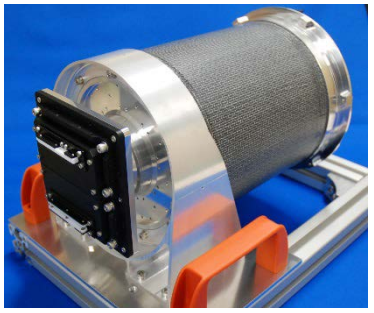
Space science mission

New utilizations
New Players

# Components Developed (examples)

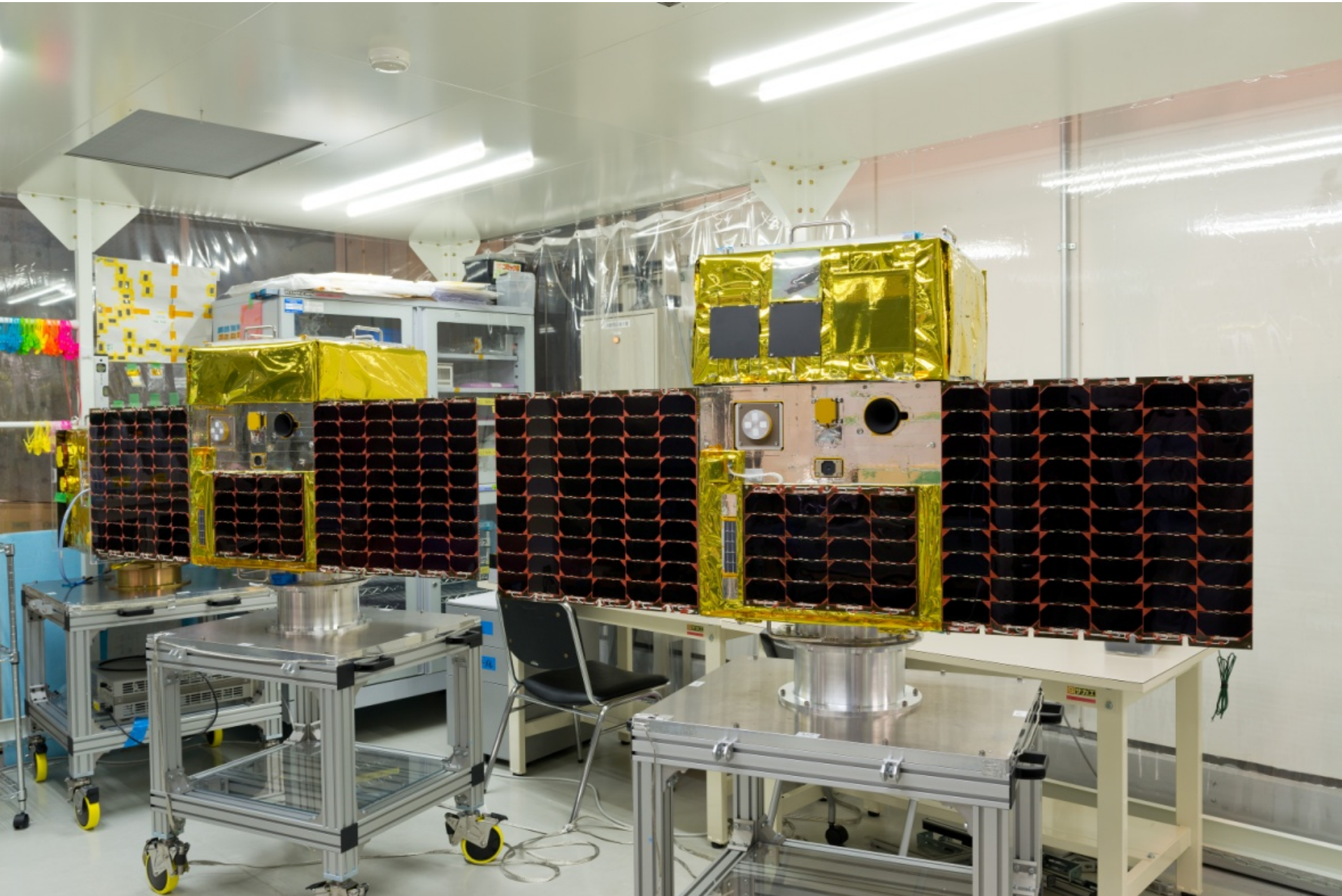
- Radiation-hardened SOI-SoC onboard computer
- Software architecture (SDK, HILS, etc.)
- Optical camera with 2.5 - 200m GSD
- Li-Ion battery and power control unit
- Low-shock lock/release & deployable mechanism
- High speed and versatile data handling unit
- High speed, low power RF transmitter （>500Mbps)
- Electric propulsion system (Ion thruster)
- Attitude control system for micro/nano-satellite
  - Fiber optical gyro, Reaction wheel, CMG, etc.
- Debris mitigation device (deployable membrane)
- Optical communication system (with NICT)





Supply chain of 170 companies re-established to reduce cost

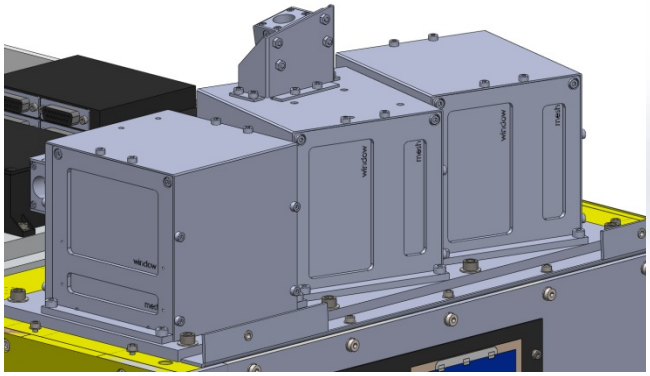
# Hodoyoshi-3 (left) and Hodoyoshi-4 before Shipment (April, 2014)

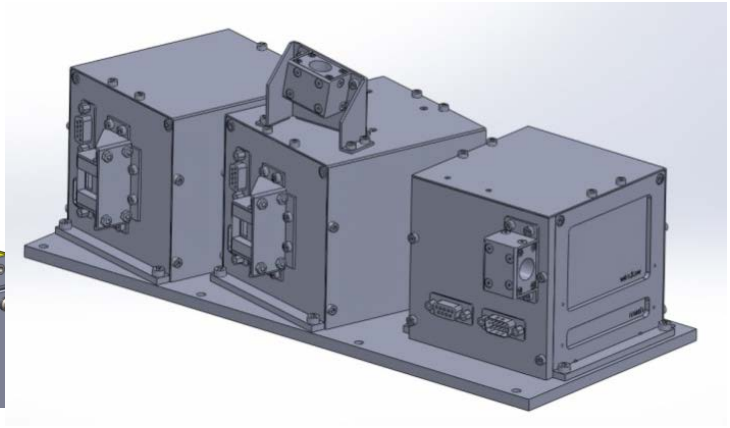



Chiba（6m GSD)
Hodoyoshi-4
(66kg)


Dubai (6.7mGSD)
by Hodoyoshi-1
(60kg)
©AXELSPACE

# “Rental Space” in Hodoyoshi 3 & 4





Provided Services:
-Electric power
-Information line
-Camera
-Windows

- Vacant spaces of 10cm cubic size, which are sold to customers
- To provide the “orbiting laboratory” or “advertisement room” opportunity for companies, researcher, public
  - Space demonstration of new products
  - Space environment utilization (micro-gravity)
  - Space science, etc.

Inside of 10cm Cubic Space

# HODOYOSHI-2（RISESAT)

**International Space Science Platform**

**Size:**
50cm
55kg

**Comm:**
S-band
38.4kbps
X-band
2Mbps

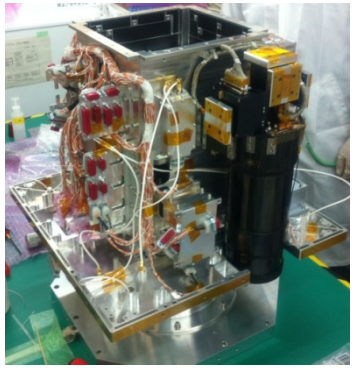
**Power:**
100W

**ACS:**
<0.1°

**Rocket:**
**Epsilon**

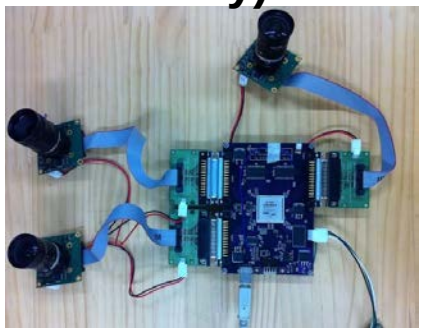
2018 launch

**High Precision Telescope- HPT (Taiwan/Vietnam)**



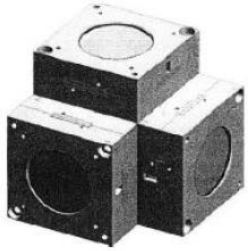
**Meteor counter - DOTCam (Taiwan(NCKU))**

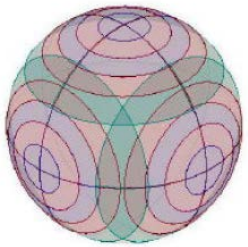
**Ocean Observation Camera - OOC (Tohoku University)**



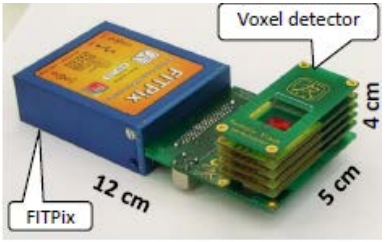
**Camera Instruments**

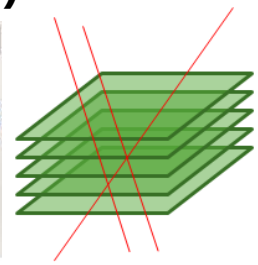
**TriTel – 3D Dosimeter (Hungary)**



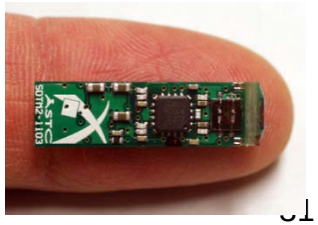


**TIMEPIX – Particle counter (Czech)**



**SDTM – MEMS Magnetometer (Sweden)**

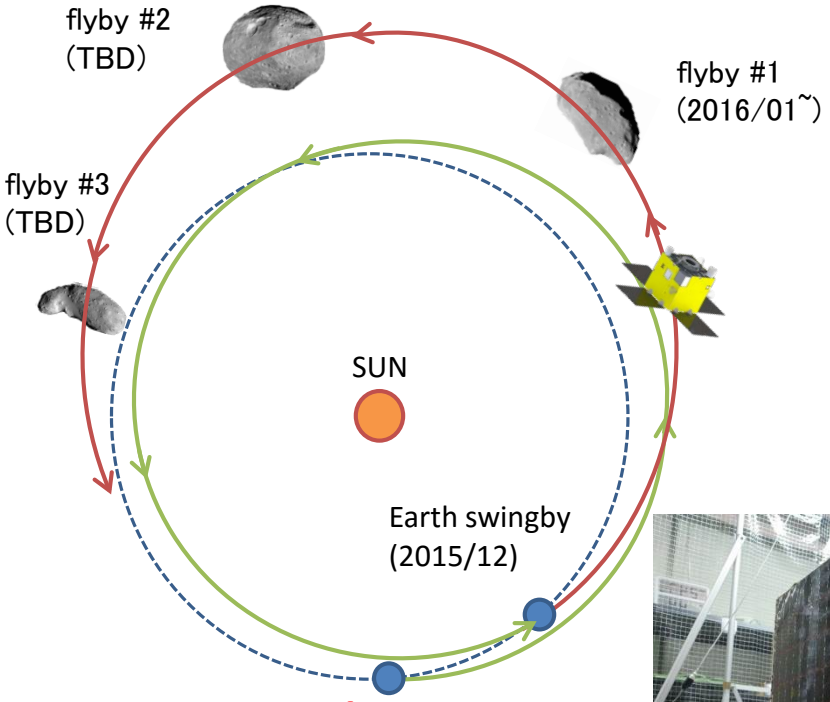


**Sensor Instruments**

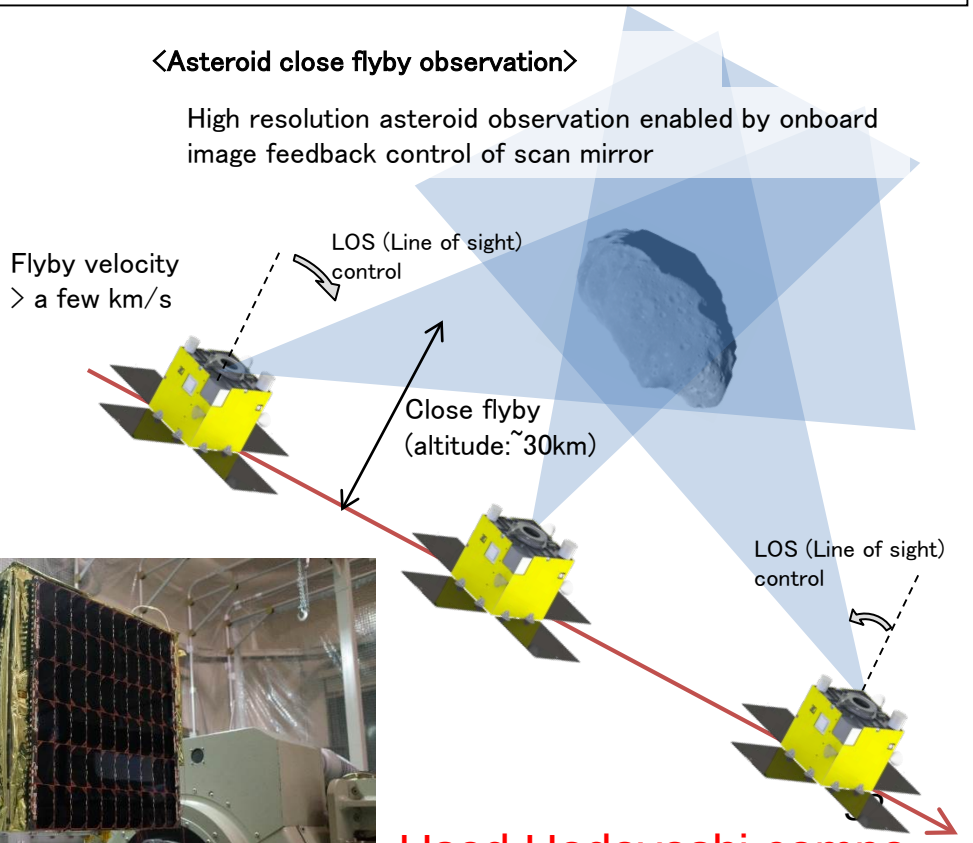
# 50kg-class deep space probe "PROCYON"

(PROCYON: PRoximate Object Close flYby with Optical Navigation)

**Developer**: **Univ. of Tokyo and JAXA** (Japan Aerospace Exploration Agency)
**Launch**: H2A rocket (together with Hayabusa-2 asteroid explorer, 2014 Dec.)
**Mission**: Demo. of 50kg deep space exploration bus system (nominal mission)
Asteroid flyby observation (advanced mission)




**Launched (2014/12, together with Hayabusa-2 asteroid explorer)**




Used Hodoyoshi compo.
Developed within 1.2 years

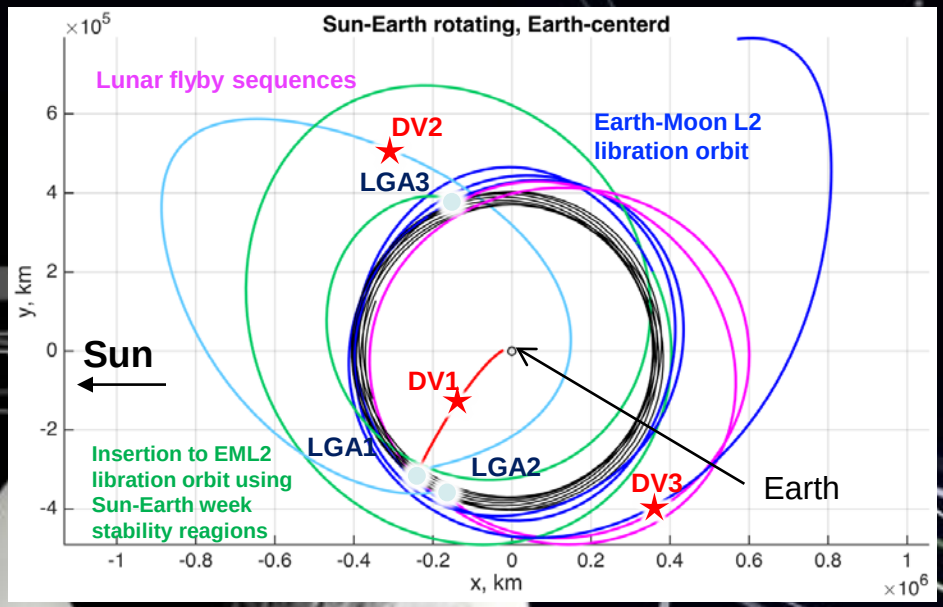
# Earth photos captured from deep space by PROCYON


Photos taken by PROCYON at close encounter of Earth in 2015/12 (one year after launch)

For detail,
Tuesday 8:45am by Ryu Funase

# EQUULEUS One of 13 EM-1 CubeSats

EQUilibriUm Lunar-Earth point 6U Spacecraft




## Mission to Earth Moon Lagrange Point

Intelligent Space Systems Laboratory, 2016/08/01

# Key Strategies

- Small-satellite size (<500kg) can aim at world top science. **How to assure frequent opportunity** is the key issue. Key strategies include:
  - Low-cost standard bus or standard design process ?
  - Low-cost launcher (dedicated launch/piggyback ?)
  - Selection of "mission level" considering cost-performance
- Micro/nano-satellite (<100kg) is very promising as:
  - Precursor mission leading to larger sized missions ("program" including several step-uping missions)
  - Excellent opportunity for human resource training
  - Some projects can even aim at top science in niche areas
- Collaboration between Space Agency-Universities has many merits

# Logic of “order”

Theoretical researchers require this but we relaxed…

$10^{-13}$

After severe discussions ….

$10^{-7}$

Engineering prof. “We can surely achieve this level.”

$10^{-9}$

“Let us compromise at this point !”

$10^{-11}$

Science professors “This is needed to aim at the top science”

$10^{-8}$

Micro/nano-pathfinder

< $ 10 M

$10^{-9}$

100-500kg-sat mission

< $ 100 M

$10^{-10}$

Strategic class mission

< $ 300 M

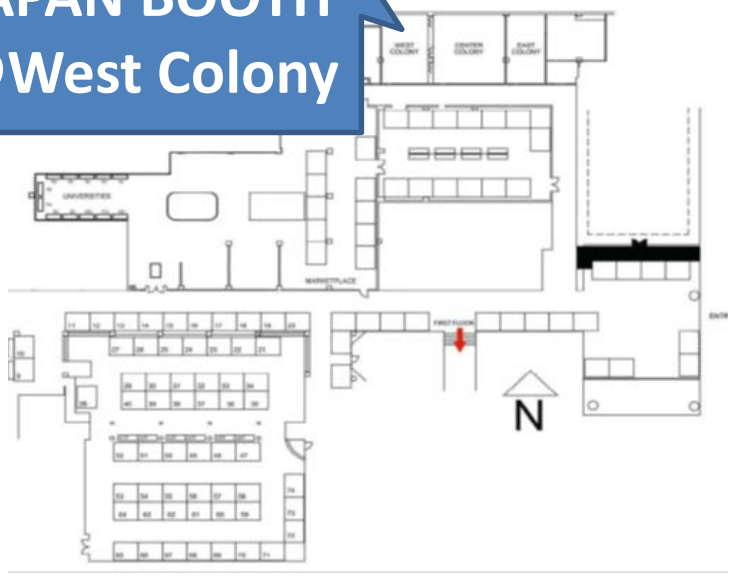
If you pursue the “perfect” objective from start, it would be hard to start as it is very difficult to get the public approval and funding.

*Quickly start with “not perfect” but “good enough” science mission!*

# METI launches “JAPAN BOOTH” at SSC 2016

- Japanese Ministry of Economy, Trade and Industry (METI) has launched **“JAPAN BOOTH”** at **West Colony**.
  - 21 Japanese companies and universities join.
- **The Portal Website (Makesat.com)** has just been released.
  - https://makesat.com

**JAPAN BOOTH @West Colony**




**Makesat.com**